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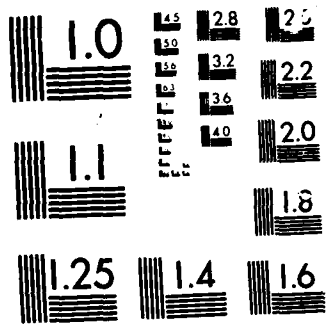

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REPORT: TR/FPO-IE/6

AD-A165 617

REVIEW REPORT ON DESIGN STUDY AND ECONOMIC ASSESSMENT OF MULTI-UNIT OFFSHORE WIND ENERGY CONVERSION SYSTEMS APPLICATIONS

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21 MARCH 1977

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APPROVED BY

Director, Engineering
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OCEAN ENGINEERING AND CONSTRUCTION PROJECT OFFICE

CHESAPEAKE DIVISION

NAVAL FACILITIES ENGINEERING COMMAND

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This report reviews the Westinghouse Advanced Systems Technology Report(s), No. AST-77-1153, Part I and Part II, dated 13 January 1977, and submitted in compliance with ERDA Contract No. E)49-18)-2330.
The review is responsive to tasking by CHESNAVFACENGCOM-FPO-ISP in (Con't)

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providing Ocean Engineering support to ERDA on Wind Energy Conversion System (WECS) studies.

The report addresses several fundamental issues which are apparent at this stage of the Westinghouse WECS study. There are:

(a) adequacy of the study plan and project management to support the ERDA objectives,
(b) adequacy of the submitted final reports (Tasks B and C) to support the other Task studies which are in progress.

Based on the overall review, specific recommendations are made with respect to the Westinghouse reports on a task-by-task basis. Reference and attachments are included.

Review Report

on

"Design Study and Economic Assessment

of

Multi-Unit Offshore Wind Energy

Conversion System Applications"

1.0 INTRODUCTION

This report reviews the Westinghouse Advanced Systems Technology Report(s), No. AST-77-1153, Part I and Part II, dated 13 January 1977, and submitted in compliance with ERDA Contract No. E(49-18)-2330.

The review is responsive to tasking by CHESDIVNAVFACENGCOM-FPO-1SP in providing Ocean Engineering support to ERDA on Wind Energy Conversion System (WECS) studies.

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(b) adequacy of the submitted final reports (Tasks B and C) to support the other Task studies which are in progress.

Based on the overall review, specific recommendations are made with respect to the two Westinghouse reports on a task-by-task basis. References and attachments are included.

2.0 WIND DATA AND ANALYSES

The evaluation of the adequacy of the wind-data presented by the contractor is based on consideration of wind-machine fundamentals and the data requirements of the design engineers. An elementary presentation of these fundamentals is made here.

2.1 WIND ENERGY

The kinetic energy of a flowing column of air is

$$KE = 1/2\ mV^2$$

and the KE per unit time is

$$\frac{KE}{t} = \frac{\Pi\rho}{2} AV^3$$

where A is the cross section area of the undisturbed air flow. This can be converted to horsepower and watts and arranged.

$$\frac{KW}{A} = \frac{\Pi\rho}{2} V^3 \times \frac{.746}{550} \qquad (1)$$

$$= 1.613 \times 10^{-6} V^3,\ KW/(FT)^2$$

$$\text{where } \rho = .002378 \text{ slugs}/(FT)^3$$

$$V = \text{wind vel. in [illegible]}.$$

As air flows through the "pr[illegible]r" of a wind machine it is slowed down and the slip-stream expan[illegible] [illegible]ractically, a propeller cannot stop the air entirely; and if it could, there would be no air flow through the propeller and no energy would be extracted. As a matter of fact, it can be shown that the maximum energy is extracted from slowing down and the stream-tube expansion of the air flow through a propeller when the interference factor "a" is one-third; and the fraction of the energy extracted is:

$$Cp = 4a(1-a)^2 \qquad (2)$$

$$= \frac{16}{27} = \underline{0.5925} \text{ max.}$$

Even then, this gives no consideration to rotation and propeller blade drag losses, Reference (1). Since we are performing an energy resource assessment, we should not invite an inflated picture of the energy available by ignoring this "non-extractable" energy factor. Consequently, Equation (1) reduces to:

$$\frac{KW}{A} = 0.956 \times 10^{-6} V^3 \qquad [2]$$

for IDEAL OPTIMUM $KW/(FT.)^2$. See Figure (1).

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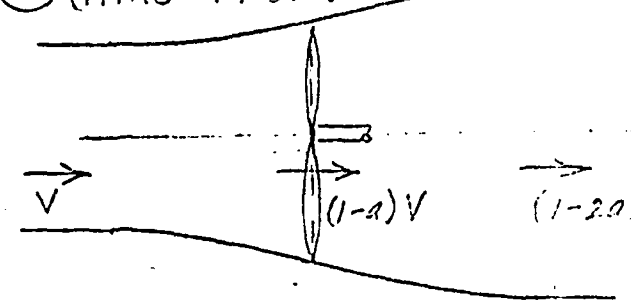
WIND MACHINE ~ IDEAL POWER EXTRACTION

Ⓐ STREAM FLOW (THRU PROP)



Ⓑ ENERGY / POWER / PWR DENSITY

$$KE = \frac{1}{2} m V^2$$

$$\frac{KE}{SEC.} = \frac{1}{2} \rho A V^3$$

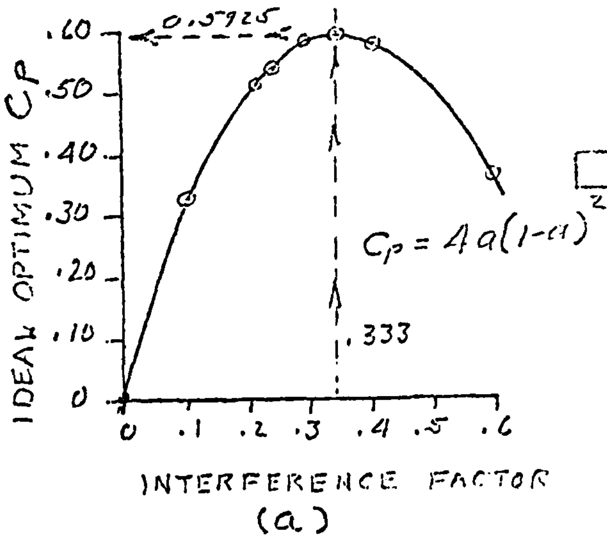
$$H.P. = \frac{\rho}{2 \times 550} A V^3$$

$$K.W = \frac{0.746}{2 \times 550} \rho A V^3$$

$$\frac{K.W}{A} = \frac{0.746}{2 \times 550} \times \rho V^3 \text{ --- [1}$$

TOTAL WIND PWR DENSI
K.W. PER $(FT)^2$

Ⓒ IDEAL ENERGY FRACTION
$(C_P = 4a(1-a)^2)$



Ⓓ IDEAL POWER DENSITY

$$\frac{K.W.}{A} = \frac{0.5925 \times .746}{2 \times 550} \times .002378\, V^3$$

$$\frac{K.W.}{(FT)^2} = 0.956 \times 10^{-6}\, V^3 \text{ --- [}$$

V = f.p.s

ρ = .002378 slugs/$(FT)^3$ at sea level and 59°F

REF. (1) : STD. HDNBK for MECH. ENGR'S

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FIG 1: WIND POWER

2.2 WIND CHARACTERISTICS

"Who hath seen the wind?
Neither you nor I:
But when the trees bow down their heads,
The wind is passing by."

The justification for this poetic intrusion is the discussion of the best manner by which wind characteristics can be visualized by the presentation of meteorological data.

Much of this discussion is based on a study of Weather Bureau records of seven years at Dayton, Ohio as reported in "Mark's Standard Handbook for Mechanical Engineers", Reference (1). The histograms of Figure (2) are rough extractions and deductions from Figure 5 of Reference 1. They were constructed to support calculations and demonstration of a needed wind-power-density method of data presentation for the WECS study.

Figure 2A is a cumulative percent exceedence presentation of wind velocity variation. It is based on Figure 5 of Reference (1); and it is similar to Figure 42 of the Westinghouse, Part II Report (WII Fig. 42). However, the WII Fig. 42 does not relate the mean wind speed curves to calm/average/windy-month occurrence as does Figure 2 of this report (and Reference 1). As a result, the Westinghouse presentation does not support some very meaningful interpretation of wind energy characteristics, as will be shown.

Figure 2B is a deduction from the percent exceedence curve of Reference 1, Figure 5. Figure 2A was constructed from Figure 2B in order to support the discussion. Figure 2B brings the occurrence of various wind-velocity-bands into the monthly distribution picture. As shown in Equation (2), this provides data upon which the V^3 power density parameter can be applied. In addition, the percent occurrence data for each velocity-band of the histogram can be related to total hours per month, or year, to bring endurance of various flow velocities into the picture in order to assess K.W.H. values of the wind-energy-resource.

Figure 2C is based on the "data" assumed in 2B, in conjunction with Equation 2, in order to present the maximum extractable kilowatt hours per month which could be expected from the "calmest", "average" and "windiest" months of an area similar to that of the Dayton study (Reference (1)).

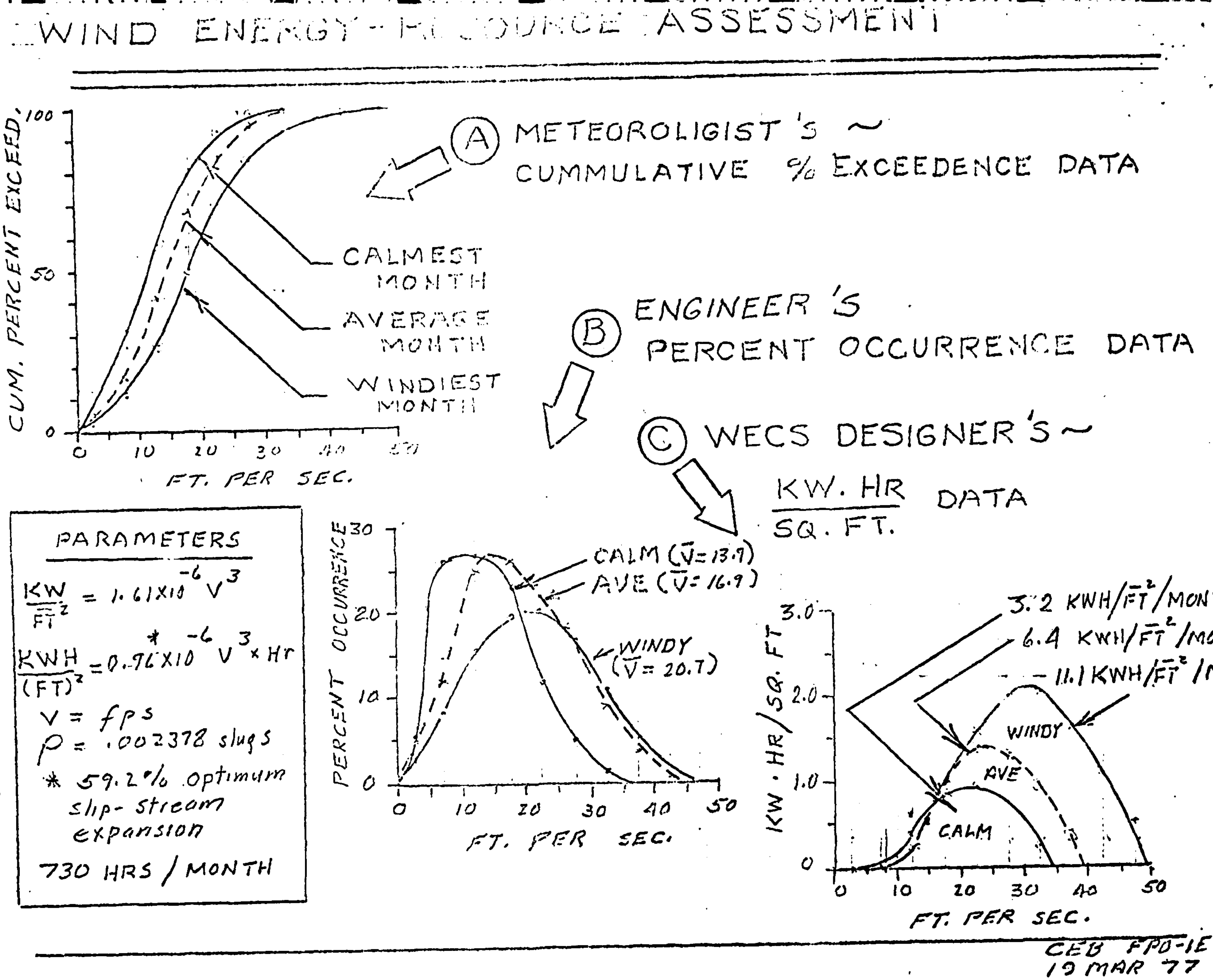


FIG. 2: WIND RESOURCE

Very meaningful descriptions of wind-energy-characteristics can be developed from the presentations of Figures 2B and 2C:

(a) the average wind velocity during the "calmest" month of the year was 13.9 feet per second, as compared to 16.9 f.p.s. for the "average month" and 20.7 f.p.s. for the "windiest" month (Fig. 2B).
(b) the K.W. Hr/(FT)^2 power density shown by Fig. 2C, indicates 3.2 K.W.H/(FT)^2/Month for the "calmest" month, 6.4 K.W.H/(FT)^2/month for the "average" month and 11.1 K.W.H(FT)^2/Month for the "windiest" month.
(c) thus, while velocities varied (+) 22%, (-) 18% around the average month; the K.W.H/(FT)^2 varied by (+) 73%, (-) 50% around the average.
(d) another very important message from Fig. 2C is the relatively insignificant K.W.H content of winds below 10 f.p.s. velocity. On the other hand, the vital significance of extracting all possible high-velocity winds is emphasized. Neither Figs. 1A, nor 1B provide this capability to "see the wind" from the WECS standpoint.
(e) the need for early consideration of requirements for power regulation is emphasized.

2.3 POWER REGULATION

The examination of Figure 2C showed a power density variation ratio which amounted to 347% from calmest, to windiest month, based on the monthly average. However, if the WECS were shut down at velocities below 10 fps (7 m.p.h., or 6 kts.), the power regulation at the peak of 2.1 K.W.H/FT ^{2}, vs. 0.2 K.W.H/FT ^{2}, creates an impressive design factor.

The study should consider power regulation as a design and economic driver very early in the program. Figure 3 shows three candidate approaches to regulation. They are:

(a) variable speed props, wind spillage, etc.
(b) pumped-water storage
(c) electrical regulation.

WECS POWER REGULATION

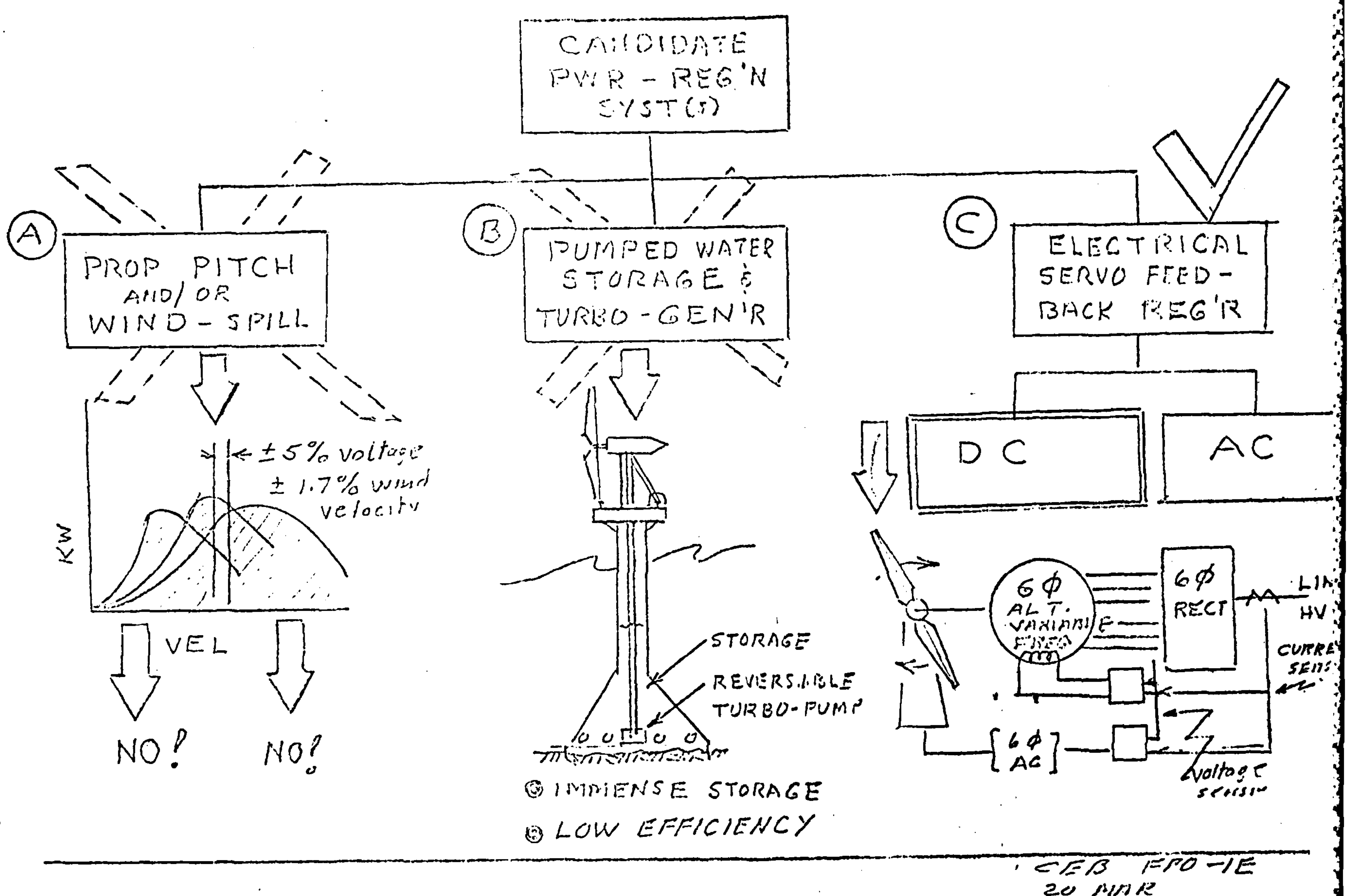


FIG. 3: PWR REG.

The candidate systems of Figure 3 should be considered and evaluated. The basis for selection or rejection should be documented in the study. The reason for a selection assessment early in the study is because of the need to identify impact on structural and plant design, transmission-cable design, utility system interfaces and economics.

2.3.1 Propeller Pitch Control and Wind Spillage. With the need to exploit all of the wind-energy-resource possible, the historic propeller-pitch control and wind-spillage methods for small wind machine power regulation are not acceptable.

2.3.2 Water Storage and Pump-Turbine Regulation. Pumped water storage methods such as shown in Attachment 1 for terrestial use, are practical as power accumulators. The necessary reversible pump-turbines exist. The efficiency losses, capital costs and operational costs are not attractive and additional electrical-regulation machinery would probably be required anyway. However, the power regulation ranges for the WECS are so great that more water storage volume and structural costs impact are involved than appears to be feasible. Still, the trade-considerations should be documented.

2.3.3 Electrical Power Regulation System. The electrical power regulation system can provide AC voltage and frequency control, or high voltage DC which would require conversion to AC at a shore sub-station. The DC, (filtered alternator source) would be highly efficient, minimize transmission cable complexity and cost and can be converted to sixty cycle AC with acceptable wave shape and power factors at a shore substation. High voltage DC is stated as "not being precluded" in the Task D, Utility Requirements Report. The trade study on this subject will mostly affect transmission cable complexity and cost and Utility Requirements; but it should be addressed at this time sufficiently to identify the system requirements and interfacing.

3.0 SUBMITTAL REPORT REVIEWS AND INPUTS

The following reviews and inputs are made on a task-by-task basis.

3.1 TASK A: "OFFSHORE SURVEY PARAMETER DEFINITION"

3.1.1 Earthquake (Section 3.10). Seismic activity will strongly influence the seafloor foundation stability, as well as structural loads. This impacts pile-design, gravity stabilized structures and anchoring systems.

3.1.2 Ocean Bottom/Soil Characteristics (Section 3.11). Add (a) subbottom profile, (b) soil properties: shear strength, gradation and consolidation, (b) Rock Properties: strength, fractures, (c) Geology: morphology and stratification. What is important is that, to the extent possible, data are obtained which are pertinent to engineering assessments.

3.1.3 Criteria used to screen candidate platform configurations should be documented in the report.

3.1.4 Selected Candidate Platforms. Artificial islands should be considered. They are practical and can be very cost effective. In addition, they may possibly be found available on a shared basis with oil production and other facilities. The possible shared use of off-shore platforms should be considered in general.

3.1.5 The materials considered for floating platforms should be listed (steel, concrete, and possibly fiber-glass and aluminum).

3.1.6 Mooring Systems (Section 4.2.5). Mooring systems should include drilled and/or driven anchors, propellant embedment anchors, clump-anchors and drag-anchors.

3.1.7 Steel Platforms (Section 4.3.1). The candidate steel fixed platforms should include in the listing:

- (a) Template platforms (as shown in the W-I Report)
- (b) Gravity Stabilized Platforms
  - (1) Self-erecting (see attachments to this report)
  - (2) Non-self erecting.

3.1.8 Operations and Maintenance Criteria. Operation and maintenance procedures should be considered in the selection of platforms in both Section 4.2, CANDIDATE FLOATING PLATFORMS, and Section 4.3, CANDIDATE FIXED PLATFORMS. Thus, two possible structural design concepts may appear in both sections:

(a) Manned systems: (Platform, Power Plant, Control Quarters, Crew Quarters, Heliport, Maintenance Shop, Crane, etc.)
(b) Unmanned system: (with stay-over housing, heliport, docking, etc.)

Although requirements for manned operations may be found economically unattractive, there will be some degree of manning required which is not yet defined at this stage of study. As a minimum, manning and logistic supply is required for inspection, maintenance and security reasons. This will generate the requirements for emergency stay-over housing and life support, communications, escape and heliport, docking and unloading facilities. The extent of manning should be treated as a parametric factor such that several levels of manning will generate plant-size and capability inputs to structural loads, safety requirements and economic analyses.

3.2 TASK B AND C: "METEOROLOGICAL AND OCEANOGRAPHIC SURVEYS"

The environmental-zone maps and data in this Report are excellent. The treatment of environmental data is generally excellent from the standpoint of structural design. There is, however, a potential data problem from the standpoint of energy-resource assessment and power regulation considerations, which may impact the feasibility study significantly.

3.2.1 Meteorology. The data and presentation-format for depicting Wind Characteristics, for the WECS plant-design, is not considered adequate. The nature of the requirements and the reasons for obtaining additional data were discussed in some detail in Section 2 of this review. Reference 1 provides some significant insights as to the wind characteristics which were analyzed from Dayton, Ohio data. Some examples of these meaningful observations are extracted here:

(a) "Prevailing winds" blew approximately five days per week. They contained about 25% of the total wind energy.

(b) "Energy winds" blew approximately two days per week. They contained approximately 75% of the energy. Even in a calm summer month, 70% of the wind-energy came from winds which blew only 42% of the time.

(c) The wind of highest energy blew at velocities of about 2.3 times those of the prevailing winds (about 10 m.p.h. higher velocities).

(d) For each month, the energy of the varying winds was approximately double that of the monthly total average wind energy.

(e) The mean "prevailing wind" velocity was 2 m.p.h. less than the average monthly velocity.

(f) The windiest month of a year showed velocities about 1.75 as great as for the calmest months and a K.W. energy 4.5 times greater.

The reviewer believes that the contractor has acquired all of the meteorological data required and has made an excellent presentation of most of it. He should, however, put the wind velocity and occurrence data in a form such as shown in Figure 2 so that the energy-resource assessment and power-regulation variations can be useful in the WECS Plant Design, economic studies and Utility Interface evaluations.

3.2.1.1 On page 15 of the report, the equation has a typo error. Power density is in watts per square foot.

3.2.1.2 The vertical wind velocity profile should be so called.

3.2.1.3 The application of the gust factor multiplier should be described.

3.2.2 Oceanography.

The oceanographic survey data is well treated for support of structural design purposes except for:

3.2.2.1 Wave Height and Number of Waves. The designer needs information as to the estimated size of waves and the number of waves in each size-range, over the design life of the structure, for fatigue analyses purposes. In some regions the fatigue considerations turn out to be a major design driver.

3.2.2.2 Marine Fouling Drag Effects. The discussion of marine fouling drag effects is not adequate. If it is kept in the report, it should be expanded to avoid misleading a designer who uses the drag information provided there. Drag coefficients as a function of roughness can be expected to run higher than $C_D = 1.0$, as high as $C_D = 1.2$, or greater (Reference (2)). In addition, the physical build-up on structural elements requires dimensional information in terms of build-up-thickness, distribution of the thickness-profile as a function of water depth, water clarity, temperature, etc. The effect of build-up on the inertia load area is also needed by the designer. This subject should be investigated and the data published in the report should be supported by references. Whether or not the subject is treated here, or under a design task, is a matter of option.

4.0 UTILITY REQUIREMENTS

The report-draft identifies basic requirements which include universal requirements such as operations, maintenance, supervision, safety, etc.

With special consideration to the desire to avoid full time manning of these offshore plants, emphasis should be made on the subject of security with respect to trespassing, vandalism and sabotage.

The draft-report establishes the technical requirements for electrical voltages, voltage control and frequency control. This subject of power regulation, in conjunction with the prior review of the wind energy resource characteristic will be summarized briefly below with respect to TASK H, Design of WECS Plants.

5.0 TASK H - DESIGN OF WECS PLANTS

The draft-report on this task does not purport to discuss the subject of power regulation at this time. However, the reviewer considers this to be a subject which should be considered at an early stage of the study in order to ascertain what form of power regulation is feasible and what mode will become the baseline concept. This baseline decision can impact structural design, WECS plant design, transmission cable design, utility interfacing, and economic assessments. The reviewer's specific inputs have been covered previously in discussing wind characteristics and wind energy extraction.

6.0 SUMMARY AND RECOMMENDATIONS

6.1 The present status of the submitted Reports indicates a good approach to parametric design as a method of reducing the number of combinations and permutations of study variables.

6.2 The TASK B and C environmental reports are generally excellent. However, they are deficient in the presentation of wind characteristics in a format significant to the Plant Designer and the power regulation engineer. Since the back-up tabulation of data used in the velocity distribution and power density curves is not given, the engineer cannot re-format the data to meet his requirements (as in the re-work of Reference (1), Figure 5, which the reviewer performed as an example).

6.3 The reviewer is left with the impression that the study still suffers from a shortfall in the logic of the study plan and/or a gap in the study management in integrating the several parallel and ongoing efforts. Specifically, this impression is created by several issues which surfaced in the review and which have been discussed in some detail.

(a) Has Task H, "Design of WECS Plants" produced the requirements for environmental data such as wind characteristics which are significant to structural loadings, aerodynamics and energy-conversion system design? Has this task developed requirements for platform motion data which is significant to rotor design? Are the platform analyses engineers aware of the rotor blade sensitivity to platform motions?

(b) Are the Utilities Engineers on Task D aware of the wind power variation spectrum to the extent that they are developing power regulation options and cost trades as Plant Design criteria?

(c) Are input/output lists and milestones established by the Project Management to integrate the parallel efforts of the study task-teams?

The reviewer recognizes, in posing these questions, that the WECS Part I draft reports are merely outlines and not an indication as to the depth of work accomplished, nor of the contractor's project management and integration plan.

6.4 The inputs and recommendations made in this review are made on the basis of offering ERDA whatever ocean engineering assistance that it may deem to be useful. The extent of discussion and evaluation is more a reflection of the reviewer's interest in the project than a criticism of the work being accomplished.

Since the calculations and curves presented in the review have not been checked, they should be treated as examples until they can be verified.

References

(1) Baumeister "Marks', Standard Handbook for Mechanical Engineers", McGraw-Hill; "Windmills".

(2) Miller, B.L. "The Hydrodynamic Drag of Roughened Circular Cylinders" Paper No. 9, The Royal Institution of Naval Architects, Spring meeting 1976.

* ATTACHMENT (1)

New self-setting drilling/production platforms have economic advantages

The new units may turn some fields with marginal reserves into money-makers

Using the basic principles of its mat-supported drilling rigs, Bethlehem Steel Shipbuilding has developed drilling/production platforms that may soon become important factors in some of the economic equations of the offshore oil industry. There are five good reasons for this assertion:

1. **The platforms are self-setting.** A portable jacking package—which Bethlehem supplies—can install them, even in moderately rough seas, with no marine assistance other than tugs.

2. The new units are permanent gravity structures and *do not require piling to pin them to the sea floor.* The mats have skirts which bite into the bottom and contribute to the unit's resistance to lateral displacement.

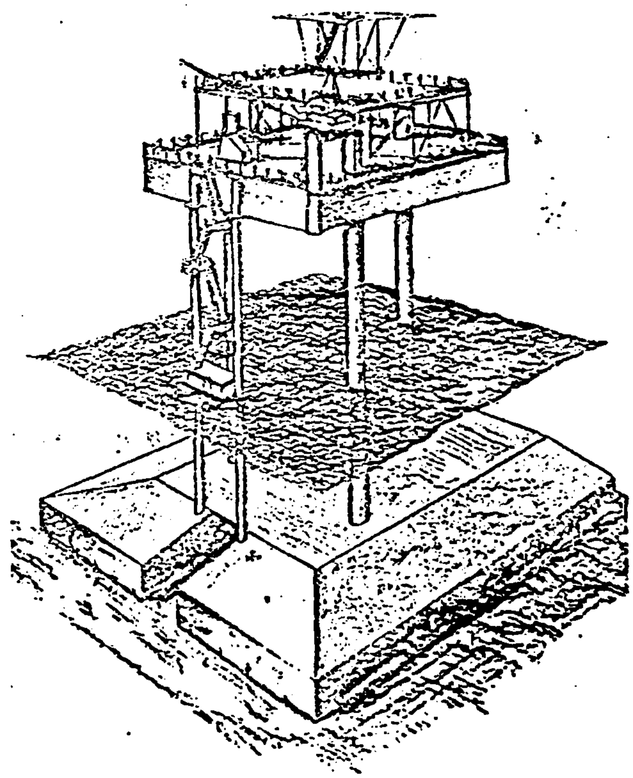
3. The platforms have sufficient storage capacity in the mat to enable an operator to commence production of oil in some areas without waiting for a pipe line. This is an important advantage because it usually takes at least two years to obtain permits and construct a pipe line. The oil produced during this interim period which could possibly amount to as much as, say, 20,000 bbl per day, might prove to be the vital factor in the economics of a particular field.

4. ***The units are recoverable.*** Should a field become depleted or unprofitable the structures can be refloated and moved to another location at little expense. This minimizes the risk the operator must take when he decides to develop a field with questionable reserves.

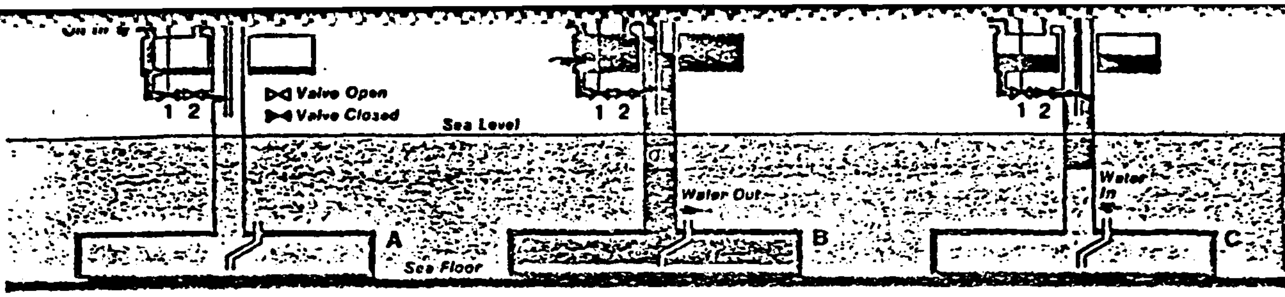
5. **In most areas, the platforms can be installed throughout the year.** Bethlehem engineers point out that once the mat is lowered beneath the effect of waves, it exerts a dampening force on heave and surge.

DEVELOPMENT OF THE PLATFORM

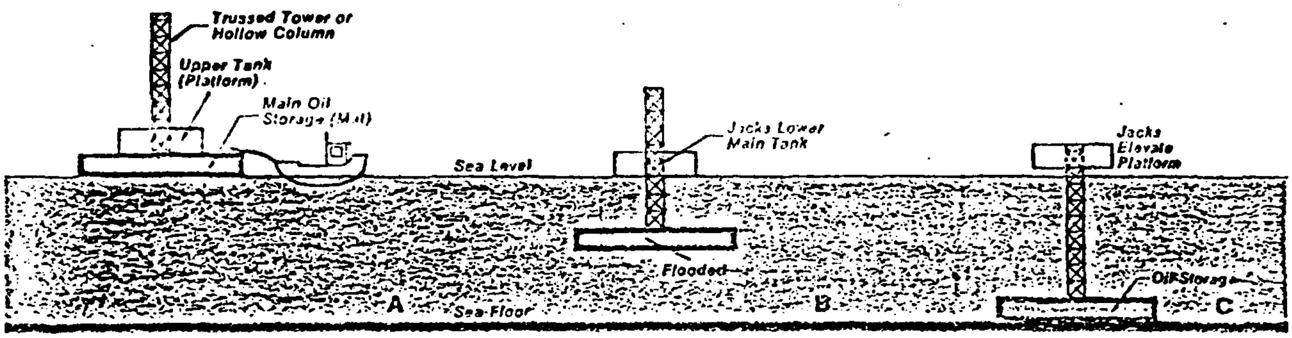
When Bethlehem officials sensed a softening in the drilling rig market brought on by governmental controls, they set out to develop new products that would penetrate other markets. They felt that any effort along this line should be based on the company's existing facilities and the technical know-how and expertise of the employees. This logically led to an effort to find new applications for



SELF-SETTING FULLY-RECOVERABLE PLATFORM designed for drilling/production/storage in water depths ranging to 243 feet. The unit is erected with portable jacks and requires no marine equipment other than tugs if it is to be moved to another location. Two units of similar configuration are under construction for the U.S. Navy and U.S. Air Force. These units will be used as towers, and the upper platform will be removed after the mat has been set.



DISPLACEMENT SYSTEM FOR UNDERWATER OIL STORAGE. For extra-high discharge rates (A) The tank is emptied of oil and flooded with seawater. Valve 1, interlocked with the discharge system, is closed. Floating controlled valve 2 is open. (B) Tank filling. Oil fills the top tank first. Overflow then fills the main tank and column. The rising column of oil closes valve 2. The discharge system is inactive, so valve 1 remains closed. (C) Pumping out. The pump suction in the column leg empties the lower tank first. Valve 1 opens when the discharge system is activated. Valve 2 opens as the oil level in column lowers. System is designed to insure that no oil will remain in the lower tank. Since the pump suction is positioned above sea level, no water can be discharged with oil.



HOW THE PLATFORMS ARE SET. As the tug approaches the site, the mat is lowered into the water. At the site it is jacked onto the sea floor and the upper platform section elevated to provide the proper air gap. The portable jacking package is then removed.

first look at the new unit in operation. The owner is the U.S. Air Force; and in this instance, the only function of the platform section will be used to float the structure to the installation site. Once on location the platform will be floated off and returned to the yard, leaving the leg extending above the water to house an electronic combat simulator.

A similar unit will be constructed for the U.S. Navy.

At the present time, Bethlehem is in the final stages of contract negotiations for a shallow water unit. The only remaining hurdle is to obtain U.S.G.S. Certification.

This unit which will have a 9,000-bbl oil storage capacity will be installed in 65-ft waters in the Gulf of Mexico.

OPERATION

The sequence of operations for moving one of the self-setting platforms onto or off location follows this general pattern: It is anticipated that drilling and production equipment will be loaded onto most of the units before they leave the shipyard. Also, on board will be a portable jacking package.

Tugs tow the rig to the location and enroute, the mat is gradually jacked down so that upon arrival, it is near bottom. As the tugs hold the unit on location the jacking continues. After the mat engages the bottom, the platform section is elevated above the surface of the water. When the proper air gap is obtained, the platform is welded to the legs and the jacking package is removed and shipped back to the yard. If the owner desires to move the unit to a different location the above sequence is reversed. Aside from tugs, no additional marine equipment is required to complete any of the operations.

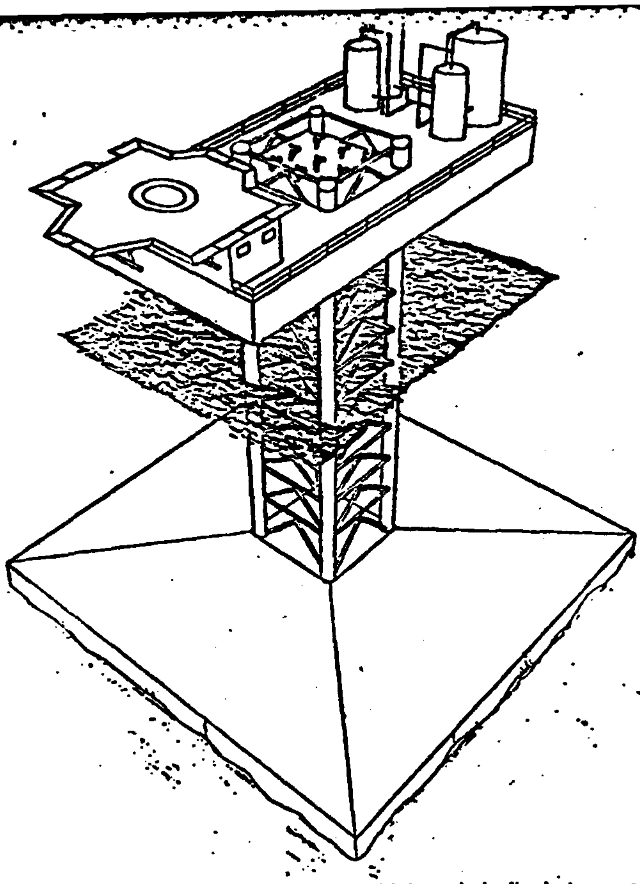
HOW SAFE ARE THE PLATFORMS?

Bethlehem is quite confident the new self-setting platforms will withstand any sea conditions for which they are designed. The company has considerable data to back up this idea, having constructed nearly all of the mat-supported jack-up drilling units in operation today. But in addition, the company has gained considerable experience with mat-supported production units and underwater oil storage facilities. The company introduced the first production unit to the offshore oil industry in 1950 and the first storage facility in 1960. Since that time, the company has installed more than 20 tank battery barges, marine gas compressor stations and underwater storage units built to this design.

Bethlehem officials are proud of the record achieved by these production units. Not one has been lost or destroyed despite the fact that at least one of the units has been within the area of influence—if not in the direct path—of every hurricane to hit the Texas/Louisiana/Mississippi Gulf Coast since 1950!

THE FUTURE

Bethlehem officials say the new self-setting platforms can be designed for much deeper water, and they freely predict that the time will come when the units of this configuration will be installed at the very edge of the Continental Shelf. Also, they say that storage can be increased to 1 million bbls per unit.



SHALLOW WATER PLATFORM. Bethlehem is in final stages of contract negotiations for this unit which will be set in 65 ft water in the Gulf of Mexico.

mat-supported jack-up structures which the company has supplied to the oil industry for more than a quarter of a century.

The need for a moderately priced, recoverable platform. When Bethlehem studied the market for offshore production platforms, it found a genuine need for a moderately priced, fully recoverable platform that could be used for drilling, production and, where required, storage. Such a unit is needed for fields—or prospective fields—with marginal or questionable reserves and for producing fields where there are no pipe lines or shore facilities to handle the oil.

DESIGN FEATURES

From the beginning, Bethlehem engineers felt confident that mat-supported, jack-up structures could be designed to meet these basic needs in virtually any water depth, provided the price could be held to a moderate level.

They directed their energies along two lines to achieve this aim. First, they set out to hold the anticipated cost of the unit at a minimum level; second, they found ways to minimize the cost of installing the unit at sea.

Holding down the cost of the unit. The first measure directed toward this end was to remove all machinery from the basic structure. (Only the drilling and production machinery supplied by the owner is installed.) Even the jacking system was removed to be replaced by a portable jacking system that will be supplied by Bethlehem as required.

of the structure was to provide different designs for different water depths, environmental conditions and customers' requirements. Where oil storage is not required, for example, the mat can be lighter because the buoyancy of the oil is no problem and the storage space is not needed.

Minimizing installation costs. One of the major cost considerations of conventional platforms is the cost of construction at sea. Bethlehem engineers say this cost is negligible for the new platform. The drilling and production equipment can be installed for little cost at the shipyard, and once on location, the portable jacking system sets the unit. The only marine equipment needed is the tug (or tugs) which tow the unit and hold it on location during the jack-up operation. After jack-up has been completed, the upper platform is welded to the legs and the jacking package is returned to Bethlehem.

Components. As shown in the accompanying illustrations, the self-setting platforms vary in size, configuration and even function. Yet all of them are based on the basic principles employed by Bethlehem in the design of its jack-up drilling rigs. The units have three basic components: the mat, the legs and the platform.

(1) The mat. This is a barge-like structure which is lowered to the sea floor to support the entire structure. Normally, it is ballasted with sea water unless it is used for oil storage. On all of the units designed thus far, the mats have a 2-ft skirt which will bite into the sea floor to increase the unit's resistance to lateral movement.

(2) The platform. The buoyant, barge-like platform provides most of the buoyancy during transit to the location. Once the mat has been jacked down on location, the platform which will contain drilling and production equipment is jacked up above the wave height and welded off to the leg or legs. The hull may provide any variety of drilling and production equipment, crew quarters, etc.

Shallow water design. This is a four-column mat-supported jack-up designed for shallow water. The mat which measures 110 x 92 x 7½-ft has a 2-ft skirt. The four columns are 6 ft in diameter and 128 ft long. The platform is 90 x 78 x 11½ ft.

Platform for 125-ft water depths. This unit has four 8-ft diameter columns 192 ft long. The skirted mat measures 160 x 105 x 8 ft and the platform measures 160 x 80 x (about) 16 ft. The unit has a 20 x 20 ft conductor pipe support tower at the center which is 165 ft long. Its purpose is to provide lateral support for the conductor pipes.

Platform for 197-ft water. This unit has a single 40-ft square trussed column at the center. Its length is 274½ ft. The dimensions of the mat are 200 x 200 x 10 ft and the platform will be 154 ft long, 80 ft wide and have a depth of 16 ft. The opening for the column will be 45 x 45 ft.

Platform for 243-ft water. This unit has a 45-ft square trussed column 313-ft long. The mat measures 190 x 190 x (about) 10¼ ft and a platform measuring 150 x 110 x 18 ft. The platform will have a 40,000 bbl oil storage capacity.

PLATFORMS ON ORDER

The first test of the basic design principle will get underway in February. Although the structure will have no petroleum application, it will provide industry with the

Attachment (2)

Energy from the Wind

Testimony before the Subcommittee on Energy Research and Water Resources of the Interior Committee, U.S. Senate, 2 March 1976

Statement by E. Wendell Hewson

Department of Atmospheric Sciences

Oregon State University, Corvallis, Oreg. 97331

1. Introduction

The research on which this testimony is based was commenced by the writer in 1971 with the sponsorship of the four Oregon PUDs (Peoples' Utility Districts), those of Central Lincoln, Tillamook, Clatskanie, and Northern Wasco County. At that time, this project was the only externally sponsored wind energy research in the United States. This group of sponsors was joined in 1975 by the Eugene Water and Electric Board. A program of wind prospecting in selected areas of the Pacific Northwest is also being conducted by the writer and his associates jointly with and under the sponsorship of the Bonneville Power Administration.

The statements made in this testimony about wind energy potential in the Pacific Northwest are based on the above research. The statements on wind energy potential over the whole of the United States are derived from the Energy Research and Development Administration (ERDA) sponsored Wind Energy Mission Analysis, which has been conducted since May 1975 by Oregon State University, the four Oregon PUDs, the Bonneville Power Administration, and other groups working in cooperation with the Lockheed-California Co., the prime contractor.

2. Is the wind available?

a. The Pacific Northwest

The wind data available indicate that there are a large number of sites with the strong and persistent winds needed for the generation of electrical power. For example, Fig. 1 shows the Oregon coast and the depth of offshore waters. Winds along the coast and offshore are very good, especially during the winter, when the peak power loads occur. Consider the winds over Yaquina Head, which projects into the Pacific Ocean and lies a few miles north of Newport, and those at Cape Blanco on the southern Oregon coast. Figure 2 presents three wind speed duration curves for these areas. These curves show the number of hours per year that the measured winds exceeded the indicated values. The winds at the U.S. Coast Guard Stations at Cape Blanco and at Yaquina Head, especially those at the Communications

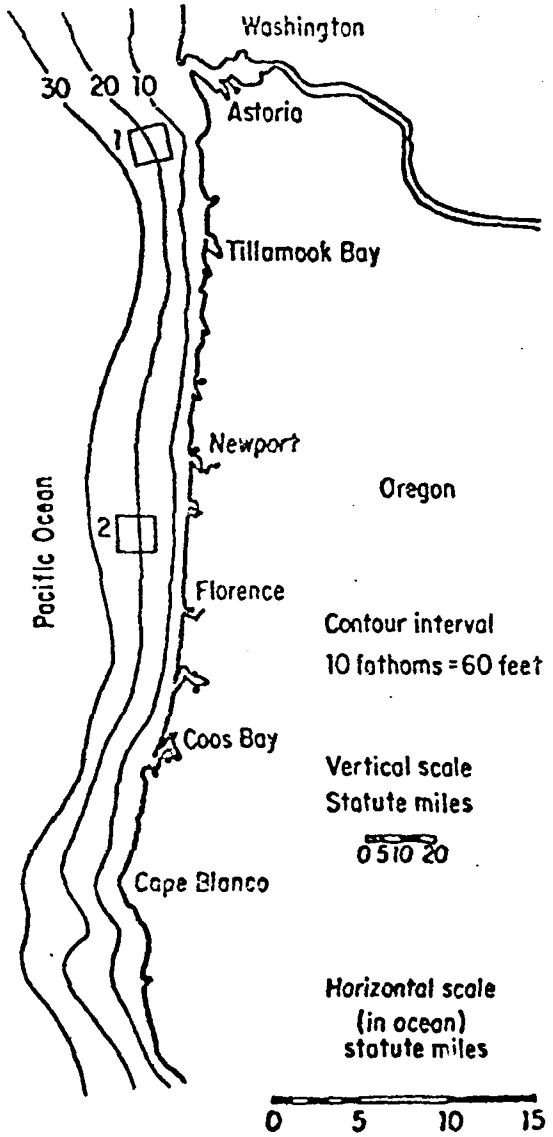


Fig. 1. The Oregon coast and the depth of offshore waters. Note the expansion of the horizontal scale relative to the vertical scale.

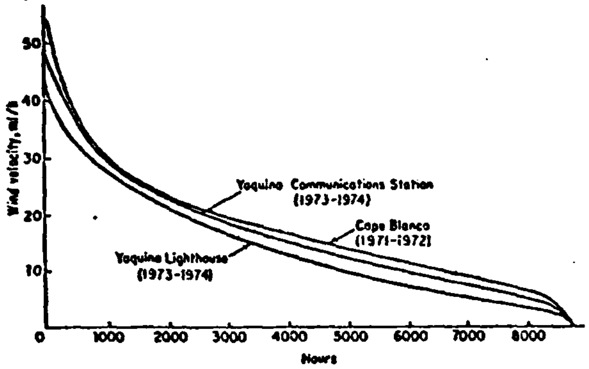


FIG. 2. Wind speed duration curves for Yaquina Head and Cape Blanco, Oreg. The curves show the number of hours per year that the measured wind speeds exceeded the indicated values.

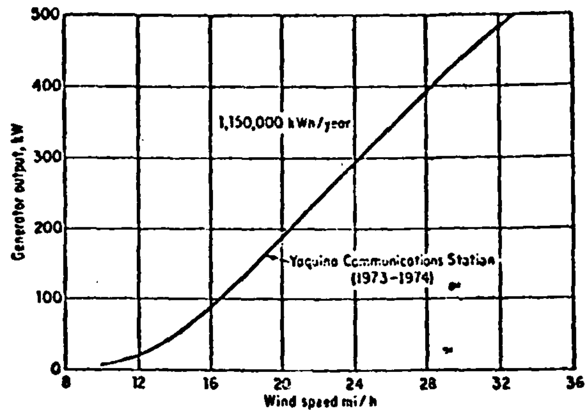


FIG. 3. Relation between generator power output and wind speed at Yaquina Communications Station, Oreg.

Station, are very favorable. Figure 3 shows that a 500 kW wind turbine there would generate over a million kilowatt hours per year. Groups of aerogenerators in the two offshore areas marked 1 and 2 in Fig. 1 would produce energy equal to that of a large conventional 1000 MW power station. The winds are equally favorable over great areas lying to the east of the Columbia River Gorge.

b. The United States

Information developed in the course of our Wind Energy Mission Analysis indicates that there are many areas with favorable surface winds in addition to the excellent ones of the Pacific Northwest. Such winds are to be found in portions of: Alaska; Hawaii; a number of the Plains states; some eastern areas, both coastal and offshore; and, in general, over much of the more than half of the United States that is mountainous. An area with a power density in the average wind of more than 300 W/m² is considered to be a first-rate site. Our charts for estimated winds at 50 m show many more good potential sites than our charts for surface winds at 10 m do, and the estimated winds at 100 m are even better, being favorable for wind power generation over most of the country.

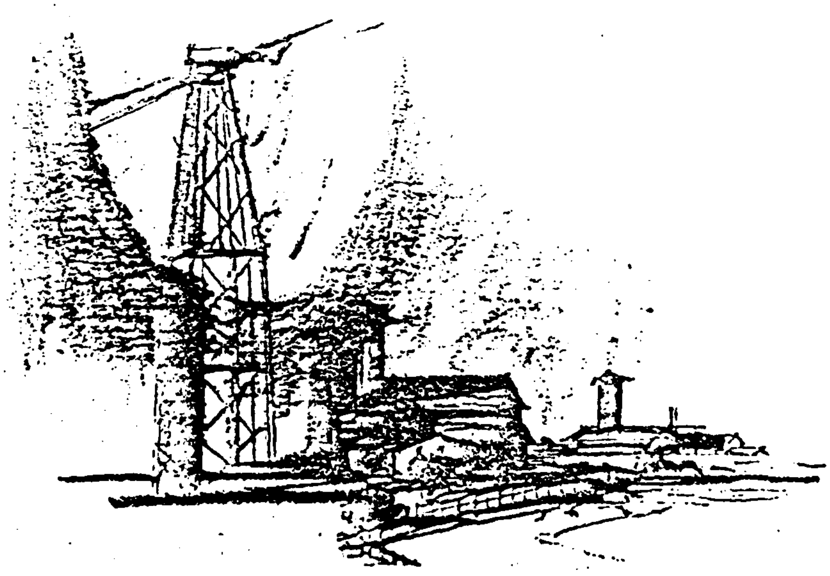


FIG. 4. Sketch of single aerogenerator as it might appear in the Great Plains.

Thus we may conclude that the winds are indeed available.

c. Future tasks

Wind power is proportional to the cube of the wind speed, so that, for example, a 20 mi/h wind will produce 8 times as much power as a 10 mi/h wind. This means that a reliable evaluation of the wind power potential of a site requires an accurate knowledge of wind speeds and their variation with height. Information of sufficient accuracy is almost totally lacking over the more than half of the country that is mountainous. A major task is to develop methods of obtaining the required information quickly and inexpensively, and without the necessity of making wind measurements at every potential wind site.

3. Is the technology available?

Electrical power has been generated in years past by thousands of small windmills. Experience with much larger units has been gained in Europe and in this country. NASA, through ERDA, now has an operational wind turbine rated at 100 kW at 18 mi/h in operation near Sandusky, Ohio.

Although a variety of models must be built and tested before going into mass production, this phase can be completed much more quickly for wind power than for most of the other alternative energy sources now being explored.

4. Are there significant environmental impacts?

Wind energy conversion systems produce no significant amounts of waste heat, noise, or air or water pollution. They would have virtually no effect on weather and climate, either local or global. Large aerogenerators, singly or in groups, may cause a sort of visual pollution, but many such aerogenerators can be located in remote areas where they would be seen by few people. There is a possibility that aerogenerators near inhabited areas may cause interference with television signals.

Wind power is compatible with multiple land use. Although relatively large areas are needed, wind power generation and agricultural production, for example, could proceed with little mutual interference. The accompanying sketches show large aerogenerators, a single one in the Great Plains (Fig. 4), and a group as they might appear in the wide open spaces of northeastern Oregon (Fig. 5).

Wind power will have fewer significant environmental impacts than nearly any of the other alternative energy sources.

5. Is the public ready for wind power development?

As part of its participation in the Wind Energy Mission Analysis, Oregon State University through its Survey Research Center conducted a nationwide survey of public attitudes toward wind power and its development. The Gallup organization of Princeton, N.J., undertook the field work on a subcontract basis. The results are summarized briefly below.

Continued research and development of wind power for electrical energy is strongly supported by Americans who are aware of the possibility of harnessing wind energy. This segment of the public feels that wind power is not only nonpolluting and abundant but is also nondepleting as well. These findings were part of the results of a public acceptance model developed and tested on a nationwide probability sample of American adults. The survey, conducted in September 1975, showed that about half of those interviewed were aware of the potential from wind energy. Even so, three out

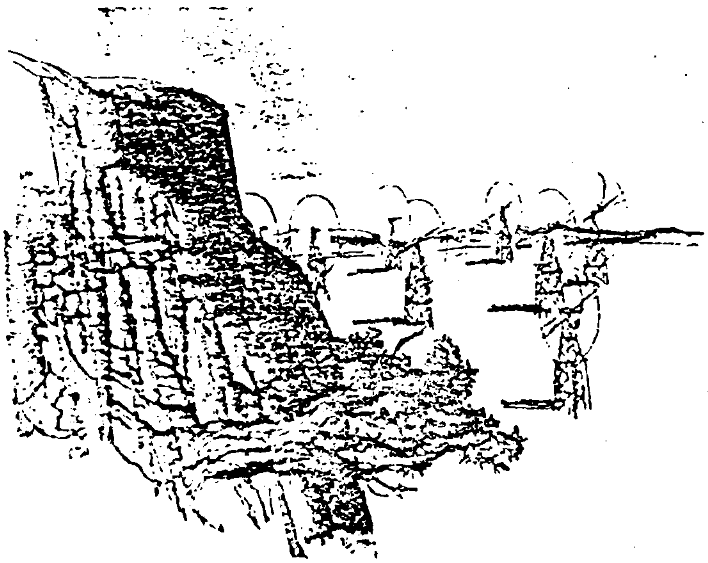
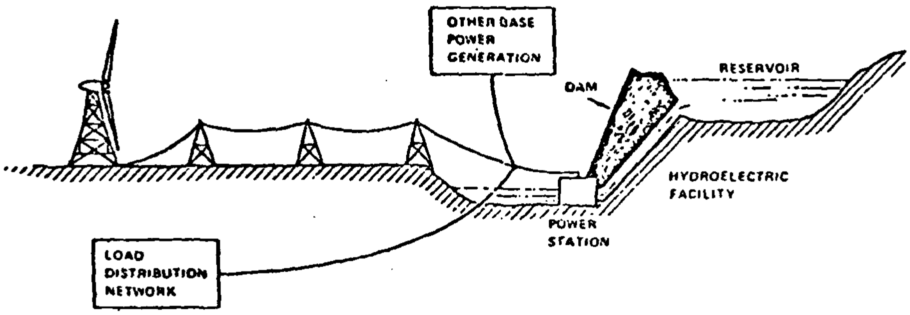


FIG. 5. Sketch of a group of aerogenerators as they might appear in the wide open spaces of northeastern Oregon.



1. HYDROELECTRIC TURBINES THROTTLED WHEN WIND ENERGY IS GENERATED
2. CONSERVES HIGH WATER AS POTENTIAL ENERGY EQUIVALENT TO THAT GENERATED BY WIND
3. HYDROELECTRIC CAPACITY INCREASED TO HANDLE HIGHER PEAK POWER AVAILABLE FROM CONSERVED WATER; HIGHER DRAWDOWN RATE POSSIBLE

APPLICATIONS:

- UTILITIES – EMPLOYED WHERE HYDROELECTRIC FACILITIES ARE AVAILABLE TO INCREASE AVAILABLE PEAKING ENERGY
- RURAL ELECTRIC AGENCY COOPS – SAME AS UTILITIES
- INDUSTRY – SAME AS UTILITIES

FIG. 6. Wind Energy Conversion System (WECS) with hydroelectric system provides inherent energy storage.

of five (60%) interviewed favored the use of wind power for electrical generation, whereas 12% were opposed. The remaining 28% had no opinion. The need for developing alternative energy sources, including wind power, was mentioned most frequently by all who were asked to explain their opinions concerning wind power.

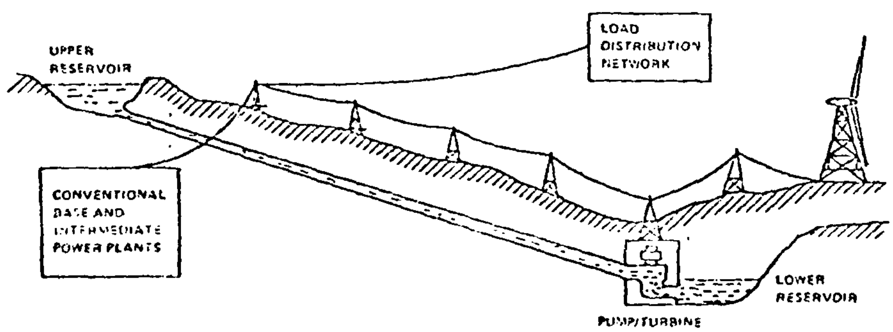
Thus it is clear that the American public is ready to support a major effort to develop wind power.

6. Is energy storage required?

Although means for storing energy from the wind are desirable, substantial use of wind energy may still be made without storage facilities. For example, wind energy may serve as a supplementary energy source and as a fuel saver to conserve our supplies of fossil and nuclear fuels.

Existing hydroelectric systems provide an excellent means for storing the output of Wind Energy Conversion Systems (WECS) as Fig. 6 illustrates. The hydroelectric turbines are throttled when wind energy is being generated; water behind the dams is thus conserved for later use, as during peak load periods. Another alternative is to construct a pumped hydro storage system, as shown and described in Fig. 7.

There are many other possible energy storage systems, such as batteries, which may turn out to have substantial promise.



1. WIND ENERGY PUMPS WATER TO HIGHER RESERVOIR DURING BASE DEMAND TIMES
2. RESERVED FLOW GENERATES POWER DURING PEAK DEMAND
3. TWO THIRDS OF THE WECS ENERGY IS RECOVERED

APPLICATIONS:

- UTILITIES WHO GENERATE USE PUMPED HYDRO FOR PEAKING POWER INSTEAD OF FUEL BURNING UNITS SUCH AS DIESELS OR GAS TURBINES
- INDUSTRIAL APPLICATIONS INCLUDE LARGE ENERGY USERS (ALUMINUM, COPPER REFINERS, ETC) WHO LOCATE REFINERIES CLOSE TO ORE DEPOSITS IN REMOTE AREAS

FIG. 7. Wind Energy Conversion System (WECS) with pumped hydro-storage provides energy storage.

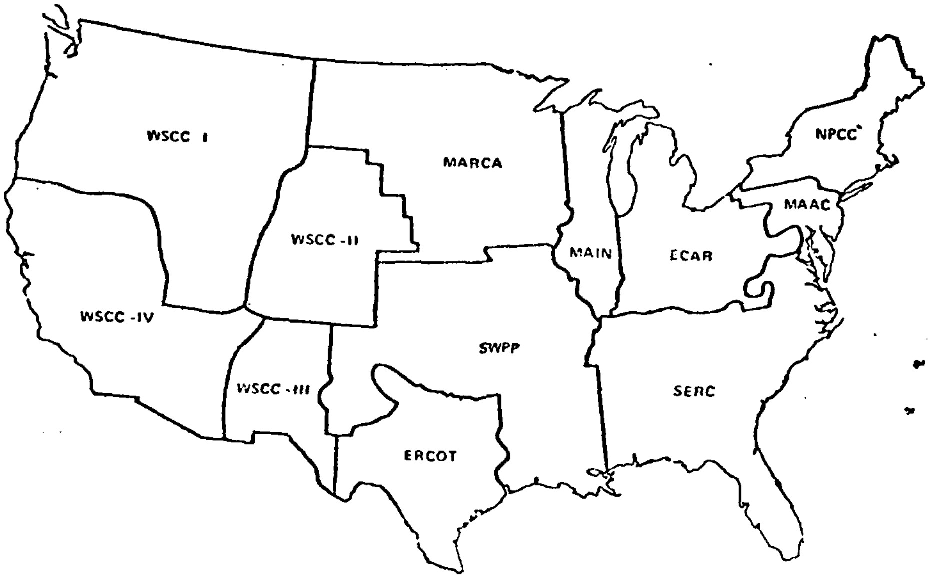


FIG. 8. Map showing electrical power regions in the contiguous states (from the Federal Power Commission).

The economics of such combined wind-hydro generating systems is examined in the next section.

7. Will wind energy be cost competitive?

One of the most direct and immediate benefits of electrical power generation from the wind will be in the application of WECS to augment hydroelectric generating capability. This prospect will be discussed first for the Pacific Northwest and adjacent areas and then for the contiguous states.

a. Pacific Northwest and adjacent areas

The extent of this electric service area, designated as the WSCC Region, and other similar areas, is shown in Fig. 8. Table 1, a projection to 1995 for the WSCC Region, presents two alternatives for augmenting hydroelectric power. If only the hydro potential of the area is developed, 3.3×10^{11} kW h will be available annually at a cost of 1.07¢/kW h. If, in addition, wind energy amounting to 1.9×10^{11} kW h/year is developed (Alternate 1) for a total of 5.2×10^{11} kW h/year (an increase of 58%), the cost of energy is projected to be 1.59¢/kW h. If, on the other hand, this increase is achieved by the use of fossil fuels (Alternate 2), the corresponding cost of energy is substantially higher, 1.96¢/kW h. There is thus a clear cost advantage in developing wind power.

b. Contiguous states

Table 2 presents data for the contiguous states. It is interesting to note that even now the net cost of wind energy in the Pacific Northwest and adjacent areas (WSCC Region), if it were being generated, would be less than the 1975 cost of fuel in the region.

c. Generating equipment

Detailed preliminary analyses indicate that the most competitive and cost effective aerogenerators will be those rated at 2–5 MW and having blades from 200 to 350 ft in diameter.

TABLE 1. Application of Wind Energy Conversion Systems (WECS) to augment hydroelectric generating capability—A projection to 1995 for the WSCC Region.

		Augmented by	
	Forecast	Wind Energy (Alternate 1)	Fossil Fuels (Alternate 2)
Hydroelectric capability	64 500 MW	64 600 MW + 87 900 MW	64 600 MW
Hydro plant factor	0.59	0.25	0.59
Annual hydro energy	3.3×10^{11} kW h	3.3×10^{11} kW h	3.3×10^{11} kW h
WECS annual energy	0	1.9×10^{11} kW h	0
Fossil fuel annual energy	—	—	1.9×10^{11} kW h
Cost of energy	1.07¢/kW h	1.59¢/kW h	1.96¢/kW h

Table 2. National effect of using Wind Energy Conversion Systems (WECS) to augment hydroelectric generating capacity in 1995.

Region (see Fig. 8)	Region Hydroelectric Capacity, MW	Annual Energy Produced, kW h/year*	Added Capacity, PF = 0.25, MW	WECS Installed Capacity, MW	WECS Annual Energy, kW h/year*	WECS Investment, dollars*	Year of Implementation with 4% Fuel Cost Increase
WSCC	64 600	334	87 900	41 000	193	13.06	1975†
MARCA	1 100	4.0	748	340	1.6	0.14	1993
SWPP	2 400	6.9	768	367	1.7	0.17	1989
ERCOT	200	—	—	—	—	—	—
MAIN	3 200	15.1	3 712	1 776	8.1	0.85	1999
ECAR	1 500	7.1	3 240	1 582	7.1	1.03	2011
SERC	17 900	61.2	10 240	5 060	22.4	3.50	2000
MAAC	5 000	30.2	8 800	4 007	19.3	1.45	1981
NPCC	22 200	89.5	18 648	8 689	40.9	3.28	1980
48 states	118 100	548	134 000	62 881	294.1	23.48	

PF is hydro plant factor.
* In billions.
† Net cost of energy less than 1975 cost of fuel in region.

8. Is there a role for small aerogenerators?

This report does not address itself to the possible contribution of small aerogenerators of the type now commercially available. There is little doubt, however, that there is an expanding market for irrigation, water heating, battery charging, etc.

9. What is the potential of wind energy as a contributor to meeting future needs?

There are many projections of the future electrical energy requirements of the United States. The analyses conducted in the course of the Wind Energy Mission Analysis suggest that wind energy is capable of supplying by 1995 on an economically competitive basis from 3% to 12% of the total United States electrical demand. The figure of 3% is based on low estimates of demand growth and cost of fuels; the 12% is based on high estimates of these.

10. Conclusions

The research reported in this statement leads to the conclusions that:

1) there are very large amounts of energy in the winds within the lowest 400 ft of the atmosphere;
2) the technology is available for making a beginning in the use of part of this energy for the generation of electrical power;
3) environmental impacts are minimal;
4) the public supports a major effort to develop wind energy;
5) existing hydroelectric systems provide an excellent means for storing wind energy at minimum cost;
6) wind energy is already cost competitive in the Pacific Northwest and adjacent areas and is projected to become so in other areas of the country;
7) there is a rapidly growing market for small aerogenerators;
8) by 1995, estimates indicate that wind power will be capable of meeting from 3% to 12% of the country's electrical power needs.

11. Recommendations

The information presented above indicates that wind energy holds very substantial promise of supplying significant amounts of electrical power in the relatively near future. Much of the advance during the recent past has been stimulated by ERDA with the assistance of NASA. Now that the potential of wind power has been clearly demonstrated, it is time to accelerate and diversify the national effort to develop wind power. To that end, it is recommended:

1) that the Subcommittee on Energy Research and Water Resources of the Senate Interior Committee propose a minimum increase in the fiscal 1977 ERDA budget of $25 million;
2) that this sum be used by ERDA to let several prime contracts, perhaps in the range from $3 million to $10 million each;
3) that the research called for in each such contract be conducted by a group made up of appropriate mixes of industries, utilities, universities, government agencies, research organizations, etc.

12. Epilog

It is believed that such contractual research, chosen and monitored by ERDA so as to complement the program originally envisioned in the budget submitted for the ERDA-NASA team, will bring a substantially increased fraction of the nation's scientific and engineering talent to bear on this urgent problem. It will therefore hasten the day when the private sector may be expected to assume the responsibilities, financial and otherwise, for developing wind energy in its many and varying aspects. •

FPO - [redacted] Appendix

Wind Systems Branch
ERDA Division of Solar Energy

July 25, 1977

7735

WIND ENERGY INFORMATION SOURCES

This partial bibliography of wind energy information sources contains a listing of recent reports generated by the Federal Wind Energy Program from its inception in 1973 to the present, and includes reports of program research projects which were managed by the National Science Foundation and the Energy Research and Development Administration. Other sources outside the program that contain pertinent additional bibliographical and technical information are also provided.

As specified in the list, most of these reports are available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.
Springfield, Virginia 22151

(703) 321-8543

Other reports are available from the U.S. Government Printing Office, which can be reached by contacting:

Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

or calling (202) 783-3238.

In a few cases, documents are available from other sources, in which case an address is provided at the end of the entry.

It should be noted that all prices listed are subject to change without notice. To order reports or obtain pricing information from NTIS or GPO, please provide the name of the report source (organization), project title, date, report number and NTIS reference number or GPO stock number (if known).

I. GENERAL BACKGROUND REPORTS & WORKSHOPS

1. *Federal Wind Energy Program, Summary Report, January 1, 1977* (ERDA-77-32) An updated overview of the ERDA wind energy program, including a discussion of objectives, program elements, major R&D activities, and abstracts of projects carried out during FY76. Includes selected wind energy reports bibliography. Available from U.S. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402; $1.15. 56 pages. Stock No. 060-000-00048-4.

2. Summary Report, *Federal Wind Energy Program,* October 1975. A brief overview of the Federal research and development activities in the field of wind energy and abstracts of the individual projects which comprise the program. Available from NTIS; $5.00. 78 pages. Order ERDA-84.

3. NSF-RANN-75-051 *Wind Machines,* Elderidge, F.R., published by the Mitre Corporation, McLean, Virginia, October 1975. A brief survey is presented of the present status of the viability, history, and future potential of various types and sizes of wind machines that might be used to help meet future U.S. energy demands. A glossary of commonly used words and phrases is appended. Available from the U.S. Superintendent of Documents, Government Printing Office; $5.00 81 pages. Stock No. 038-00-00272-4.

4. SAND-76-5586 *Vertical-Axis Wind Turbine Technology Workshop,* held at Sandia Laboratories, Albuquerque, New Mexico, May 18-20, 1976. During the last year vertical-axis wind turbines have received as much technological attention as horizontal-axis turbines, and they are now being worked on in terms of the near problems of actual application and use. The workshop proceedings describe the wind energy program overview, the Darrieus program, other prominent vertical-axis programs, and reports of the working groups. Available from NTIS; $13.75 439 pages.

5. *NSF/NASA Wind Energy Conversion System-Workshop Proceedings,* June 11-13, 1973, Washington, D.C. A summary of fifty presentations on many facets of wind energy representing many viewpoints and observations at that time. Available from NTIS; $8.50. Order No. PB-231-341.

6. *Wind Energy Workshop #2, NSF/ERDA,* September 1975. An overview of projects and technical papers in the Federal Wind Energy Program as well as activities in a number of foreign countries as presented on June 9-11, 1975, in Washington, D.C. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402; $10.00. Stock No. 038-000-00258-9. Also available from NTIS; $17.25. 601 pages.

7. *Applied Aerodynamics of Wind Power Machines*, Wilson, Robert E. and Lissaman, Peter B.S., Oregon State University, May 1974.
Basic theory of the aerodynamics of various types of wind energy systems. Available from NTIS; $5.25. 164 pages. Order No. PB-238-595.

8. *Wind Power Climatology*, Reed, J.W., Sandia Laboratories. Available from NTIS; $3.75. 17 pages. SAND-74-0435.

9. Eleventh Intersociety Energy Conversion Engineering Conference Proceedings, Volume II. American Institute of Chemical Engineers, 1976.
Proceedings of a conference held at State Line, Nevada, September 12-17, 1976. Includes 11 papers on wind energy which contain information on: siting, wind power in Brazil, utility applications, induction and field-modulated generators, vortex devices, wind characteristics, Darrieus rotor design, small systems, Canadian wind program. Available from AIChE, 345 East 47 Street, New York, New York 10017. 1009 pages.

II. RECENT WIND ENERGY REPORTS

MISSION ANALYSIS

1. COO/2578-1/2 Wind Energy Mission Analysis Final Report. General Electric- Space Division, February, 1977. Contract E(49-18)-2578. The principal objective of this study was to assess the national potential for wind energy conversion systems. Includes an identification of high potential WECS applications, a definition of performance, operational and cost goals for WECS, an evaluation of the impact on energy users of wide-scale WECS deployment and an identification of institutional and non-technical problems associated with WECS implementation. Available from NTIS. $9.00 219 pages

   COO/2578-1/1 Wind Energy Mission Analysis. Final Report - Executive Summary. Available from NTIS. $4.00 26 pages

   COO/2578-1/3 Wind Energy Mission Analysis. Final Report - Appendices A through J. Available from NTIS. $12.75 480 pages

2. DSE/2521-1 Summary of Current Cost Estimates of Large Wind Energy Systems. Special Technical Report, Revision 1. JBF Scientific Corporation, February 1977. Contract E(49-18)-2521. Reviews ERDA-sponsored studies which estimate WECS costs, summarizes the most pertinent results, and provides a normalized view of the economics of large WECS for electric utility applications. Available from NTIS: $4.50, 62 pages.

APPLICATIONS OF WIND ENERGY
(Regional)

1. COO-2603-1 *Application Study of Wind Power Technology to the City of Hart, Michigan,* Progress Report, Asmussen, J., Fisher, P.D., Park, G.L., Krauss, O., Michigan State University, Division of Engineering Research, 31 December 1975. Contract E(11-1)-2603. Information is presented concerning wind data collections and analysis; Hart power demand and consumer usage; wind power assessment; hydro power assessment and results of preliminary economics analysis. Available from NTIS: $5.50. 103 pages.

LEGAL/SOCIAL/ENVIRONMENTAL ISSUES

1. ERDA/NSF/07378-75/1 *An Evaluation of the Potential Environmental Effects of Wind Energy Systems Development, Final Report,* Rogers, S., et al., published by Battelle Memorial Institute, Columbus Labs, July 1976. Contract #NSF-AER-75-07378. Available from NTIS: $7.50. 193 pages.

WIND CHARACTERISTICS

1. ERDA/NSF/00598-75/T1 *Evaluation of Wind-Energy Sites from Aeolian Geomorphologic Features Mapped from LANDSAT Imagery, First Results,* Progress Report, Kolm, K., Marrs, R., Marwitz, J., Fletcher, J., published by Wyoming University, Laramie, Wyoming, 1 December 1975. Contract No. AER-75-00598. This research effort relates aeolian geomorphologic features, interpreted from satellite imagery, to areas of high wind-energy potential. Preliminary results, gathered during spring and summer months, were evaluated statistically to determine the critical interrelationships of the Killpecker test area. Available from NTIS; $4.00 39 pages.

2. UCID-16967 *Preliminary Feasibility Study on Using Doppler Lidar Wind Measurements for Wind-Power Prospecting,* Porch, W.M., Sussman, S.S., published by the University of California, Lawrence Livermore Laboratory, Livermore, California, 4 December 1975. Contract W-7405-Eng-48. A preliminary feasibility study indicates that present laser transmitters and receivers are capable of ranges applicable to wind-power prospecting and site surveying. Available from NTIS: $4.00. 15 pages.

3. UCID-17157-1 *Status Report of Lawrence Livermore Laboratory-Wind Energy Studies,* Knox, J.B., Hardy, D.M., Sherman, C.A., Sullivan, T.J., published by Lawrence Livermore Laboratory, University of California, Hawaii, June 1976. Contract W-7405-Eng-48. Numerical model calculations of three-dimensional regional wind fields oriented toward identifying the location, intensity, and extent of wind energy-rich areas on Oahu are reported. The use of these calculations in planning a field data-collection program to study areas of expected high wind energy is described. Criteria for the selection of wind-energy subregions of primary interest are discussed. Available from NTIS; $3.50.

4. UCRL-50034-76-1 *Wind Power Studies: Initial Data and Numerical Calculations. Progress Report, September-December 1975,* Hardy, D.M., published by Lawrence Livermore Laboratory, University of California, Livermore, California, 15 October 1975. Contract W-7405-Eng-48. Initial data collection and numerical modeling results in wind-energy research conducted by LLL. The use of conventional and laser anemometry is described. Available from NTIS; $4.00. 44 pages.

5. UCRL-50034-76-2 *Wind Power Studies: Initial Regional Applications, Progress Report, January-March 1976,* Hardy, D.M., published by the University of California, Lawrence Livermore Laboratory, Livermore, California, 22 March 1976. Contract W-7405-Eng-48. This report describes results in wind-energy research conducted by the Lawrence Livermore Laboratory. Initial applications of available regional data in numerical model calculations are reported, and data sources and collection procedures are discussed. Available from NTIS; $4.00. 28 pages.

6. UCRL-50034-76-3 *Wind Power Studies: Field Measurement Priorities for Numerical Analysis of Wind Energy,* Progress Report, April-June, 1976. Hardy, D.M., Lawrence Livermore Laboratory. 15 June 1976. Contract W-7405-Eng-48.
Results of initial numerical studies and their role in planning the July-August, 1976 field program are presented. The acquisition, calibration, and deployment of meteorological instruments for the field program are reviewed. Available from NTIS; $3.50.

7. SAND-76-5397 *Predicting Wind Power at Turbine Level from an Anemometer Record at Arbitrary Height,* Reed, J.W., published by Sandia Laboratories 1976. Contract No. S 189-76-32.
Over relatively flat terrain, useful wind increases in proportion to the one-seventh power of height above ground. Several data collections have been assembled to verify the utility of this one-seventh power low. A minor correction for lower speeds of 2-8 m/s improves predictions but is not essential to gross power availability calculations for large turbine blades. Available from NTIS; $3.50. 10 pages.

TECHNOLOGY DEVELOPMENT

1. COO-2614-1 *Application of Composite Bearingless Rotor Concept to Wind Turbine Rotor, Progress Report, June 3, 1975-October 31, 1975,* Spierings, P.A.M., Cheney, M.C., published by United Technologies Research Center, East Hartford, Connecticut, 1 December 1975. Contract E(11-1)-2614. The objective of the program is to explore the feasibility of the Composite Bearingless Rotor (CBR) for use as a wind turbine and to evaluate several automatic control concepts designed to improve efficiency and cost effectiveness. The program consists of the design of a full-scale wind turbine, design and fabrication of a dynamically scaled model, wind tunnel experiments, and analytical studies. This report describes full scale and model designs, reviews expected performance characteristics and outlines remaining tasks. Appendices provide detailed information on design characteristics of the model. Available from NTIS; $3.50. 25 pages.

2. COO-2615-76-T-1 *Experimental and Analytical Research in the Aerodynamics of Wind Turbines,* Mid-term technical report, June 1-December 31, 1975. Rohrbach, C., Hamilton Standard, February 1976. Contract No. E(11-1)-2615.
Information is presented concerning aerodynamic design and performance technology, wind turbine parametric performance study, selection of model wind turbine configurations, and structural design of wind turbine models (Horizontal-axis, propeller-type systems). Available from NTIS; $5.50. 111 pages.

3. NSF/RA/N-75-043 *Development of an Electrical Generator and Electrolysis Cell for a Wind Energy Conversion System,* Final Report, July 1, 1973 - July 1, 1975. Hughes, W., Allison, H.J., Ramakumar, R.G. July, 1975. Contract No. NSF-AER-75-00647. Available from NTIS; $8.75 280 pages. (PB 243 909).

4. NASA-TM-X-71864 *A 100 Kilowatt Experimental Wind Turbine: Simulation of Starting Overspeed and Startdown Characteristics,* Gilbert, L., February, 1976. $4.00.

5. NASA-TM-X-3390 *Fabrication and Assembly of the ERDA/NASA 100 Kilowatt Experimental Wind Turbine,* Puthoff, R.L., April, 1976.
As part of the ERDA wind-energy program, NASA Lewis Research Center has designed and built an experimental 100 kilowatt wind turbine. The two bladed turbine drives a synchronous alternator that generates its maximum output of 100 kW of electrical power in a 29 km/hr (18 mph) wind. $4.00. 30 pages.

6. NASA-TM-X-71601 *Early Operation Experience on the ERDA/NASA 100 Kilowatt Wind Turbine,* Glasgow, J.C., Linscott, B.S., September 1976, $4.00

7. NASA-TM-X-3426 *Tower and Rotor Blade Vibration Test Results for a 100 Kilowatt Wind Turbine,* Linscott, B.S., Shapton, W.R., Brown, D., October, 1976. $4.00.

ADVANCED & INNOVATIVE SYSTEMS

1. COO-2616-1 *Investigation of diffuser-augmented wind turbines: Progess Report, June 25, 1975-December 24, 1975*, Oman, R.A., Foreman, K.M., Gilbert, B.L., published by Grumman Aerospace Corporation, Bethpage, New York, January 1976. Contract E(11-1)-2616.
The Diffuser-Augmented Wind Turbine (DAWT) is one of the more promising advanced concepts for decreasing the cost of wind energy conversion. The first results of an investigation designed to determine the most effective configurations for DAWT's and to assess their ultimate performance in large units are presented. Available from NTIS; $4.50. 64 pages.

2. COO-2617-75/1 *Feasibility Investigation of the Giromill for Generation of Electrical Power, Midterm report, April-November 1975*, Brulle, R.V., published by McDonnell Aircraft Company, St. Louis, Missouri, November, 1975. Contract E(11-1)-2617.
The cyclogiro computer program, obtained from Professor H.C. Larsen of the United States Air Force Institute of Technology, was modified to incorporate computation of blade loads for the normal operating and gust loading conditions. Available from NTIS; $6.75. 155 pages.

3. ERDA/NSF/00367-75/T1 *Innovative Wind Machines, Six Month Report, March 1, 1975-August 31, 1975*, Walters, R.E., Fanucci, J.B., Loth, J.L., Ness, N., Palmer, G.M., Squire, W., published by West Virginia University, Morgantown, West Virginia, Department of Aerospace Engineering, September 1975. Contract E(40-1)-5135.
Theoretical and experimental research concerning the evaluation of two vortex concentrator and a vertical-axis panemone device for wind energy conversion is presented. The research effort is continuing and the results reported are for the initial six-months of work. Available from NTIS; $6.75. 158 pages.

4. SAND-75-0431 *The Darrieus Turbine: A Performance Prediction Model Using Multiple Streamtubes*, Strickland, J.H., published by Sandia Laboratories. October, 1975. Contract AT(29-1)-789. Available from NTIS; $ 5.00 38 pages.

5. ERDA/NSF/993-75/T1 *Production of Methane Using Offshore Wind Energy, Final Report*, Young, R.B., Tiedemann, A.F., Jr., Marianowski, L.G., Camara, E.H., published by AAI Corporation, Baltimore, Maryland and Institute of Gas Technology, Chicago, Illinois, November 1975. Contract NSF-C993.
The work accomplished during a program to investigate the feasibility of converting wind energy to methane gas is described. The basic approach consists of using off-shore winds to drive generators which supply electricity to electrolysis cells. Available from NTIS; $6.00. 131 pages. Executive Summary. Available from NTIS. $ 4.00 29 pages.

6. SAND-76-0036 *Sandia Vertical-Axis Wind Turbine Program. Technical Quarterly Report, October-December 1975*, Banas, J.F., Sullivan, W.N., (eds.) published by Sandia Laboratories, Albuquerque, New Mexico, April, 1976. Contract AT(29-1)-789.
Information is presented concerning: review of the status of general design efforts in the areas of aerodynamics, structures, systems analysis, and testing; summary of preliminary design details of the proposed 17-m turbine/60 kW generator system for power grid application: and structural analysis and operational test results for the existing 5 meter turbine. Available from NTIS; $6.50. 113 pages.

7. SAND-76-0130 *Wind Tunnel Performance Data for the Darrieus Wind Turbine with NACA-0012 Blades*, Blackwell, B.F., Feltz, L.V., Sheldahl, R.E., published by Sandia Laboratories, May 1976. Contract No. AT(29-1)-789. Five blade configurations of a 2-meter-diameter Darrieus wind turbine have been tested in a low speed wind tunnel. The airfoil section for all configurations was NACA 0012. The parameters measured were torque, rotational speed, and tunnel condition. Data are presented in the form of power coefficient as a function of tip-speed ratio for the various solidities, Reynolds numbers and free stream velocities tested. Available from NTIS; $4.50. 61 pages.

8. SAND-76-5712 *Darrieus Vertical-Axis Wind Turbine Program at Sandia Laboratories*, Kadlec, E.G., published by Sandia Laboratories 1976. Contract No. AT(29-1)-789.
From sharing the sun, solar technology in the seventies; Winnipeg, Canada (15 August 1976). As part of ERDA's Federal Wind Energy Program, Sandia Laboratories is engaged in a technology development program for the Darrieus Vertical Axis Wind Turbine (VAWT). The application receiving current emphasis utilizes the VAWT operating at constant speed to generate electricity which is fed directly into a utility grid. The activities within the program are described. Available from NTIS; $3.50. 11 pages.

9. SAND-76-5683 *Status of the ERDA/Sandia 17-METRE Darrieus Turbine Design*, Blackwell, B.F., published by Sandia Laboratories, 1976. Contract No. AT(29-1)-789.
From International symposium on wind energy systems; Cambridge, United Kingdom of Great Britain and Northern Ireland (UK) (7 September 1976). The present status of the ERDA/Sandia Laboratories 17-metre Darrieus turbine design is summarized. Available from NTIS; $3.50. 16 pages.

10. SAND-76-0338 *Sandia Vertical-Axis Wind Turbine Program, Technical quarterly report, January-March 1976*. Weingarten, L.I., Blackwell, B.F. Published by Sandia Laboratories. August 1976. Contract No. E(29-1)-789. Describes the activities within the Sandia Laboratories Vertical-Axis Wind Turbine Program during the third quarter of fiscal year 1976. Included are the highlights of the quarter, a review of the status of general design efforts in the areas of aerodynamics, structures, systems analysis and testing; a summary of preliminary design details of the proposed 17-m turbine/60 kW generator system for power grid application, and structural analysis and operational test results for the existing 5-m turbine. Available from NTIS; $5.50. 55 pages.

FARM & RURAL USE (SMALL) SYSTEMS

1. ERDA/NSF/00603-75/T1 *Investigation of the Feasibility of Using Windpower for Space Heating in Colder Climates, Third Quarterly Report covering Final Design and Manufacturing Phase of the Project, September-December 1975,* Heronemus, W.E., published by the University of Massachusetts, Amherst, Massachusetts, December 1975. Contract E(49-18)-2365. Progress on the project and manufacture is presented by system and subsystem. Efforts are defined in relation to the project organization chart and management schedules. Available from NTIS; $6.75. 165 pages.

2. NASA TM-X-71831 *Installation and Initial Operation of a 4100 Watt Wind Turbine,* Tryon, H.B. and Richards, T., published by the NASA-Lewis Research Center, December, 1975. Available from NTIS

3. RFP-Trans-192 *Characteristics of Windmills,* translation by Rockwell International, Rocky Flats Plant, Golden, Colorado, 1976. The specifications and prices of ENAG wind powered electric generators with capacities of 4000 watts, 1200 watts and 2500 watts are listed. Available from NTIS; $3.50. 6 pages.

4. NSF/RANN/SE/AER-74-00239 *Study of Alaskan Wind Power and Its Possible Applications, Final Report, May 1, 1974-January 30, 1976,* Wentink, T. Jr., published by the University of Alaska, Geophysical Institute, February 1976. Contract NSF-AER-74-00239. Available from NTIS; $7.50. 139 pages. Order No. PB 253 339.

100 KILOWATT SCALE SYSTEMS

NASA-TM-X-71890 *Large Experimental Wind Turbines-Where We Are Now,* Thomas, R.L., March 1976. $4.00. pages.

III. REPORTS PREVIOUSLY LISTED - NASA

The following technical memoranda were published by the NASA-Lewis Research Center, Cleveland, Ohio and are available from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

1. NASA-TM-X-71523 *Status of Wind Energy Conversion, Final Report.* Thomas, R.L., Savino, J.M., speech given at a RANN (Research Applied to National Needs) Symposium held in Washington, D.C. 18 November 1973. Available from NTIS; $4.00. 9 pages.

2. NASA-TM-X-71605 *Brief Summary of the Attempts to Develop Large Wind-Electric Generating Systems in the United States*, Savino, J.M., speech given at Conference on Wind Energy, Stockholm, Sweden, 29 August 1974. Available from NTIS; $4.00 16 pages.

3. NASA-TM-X-71634 *Wind Energy Developments in the 20th Century*, Vargo, D.J., presented at Fourth Annual Regulatory Information Systems Conference, St. Louis, Mo., September 1974.
Wind turbine systems of the past are reviewed and wind energy is re-examined as a future source of power. Various phases and objectives of the Wind Energy Program are discussed. Conclusions indicate that wind generated energy must be considered economically competitive with other power production methods. $3.75. 29 pages.

4. NASA-TM-X-71585 *Preliminary Design of a 100 kW Turbine Generator*, Puthoff, R.L., Sirocky, P.J, 1974. $4.00. 22 pages.

5. NASA-TM-X-3198 *Structural Analysis of Wind Turbine Rotors for NSF-NASA MOD-0 Wind Power System*, Spera, D.A., March, 1975.
Preliminary estimates of vibratory loads and stresses in hingeless and teetering rotors for the proposed 100 kW wind power system are presented. Stresses in the shank areas of the 19 meter (62.5 foot) blades are given for static, rated, and overload conditions. Available from NTIS; $3.75. 39 pages.

6. NASA-TM-X-71701 *Plans and Status of the NASA-Lewis Research Center Wind Energy Project*, Thomas, R., Puthoff, R., Savino, J., Johnson, W. Speech given at the Joint Power Conference, Portland, Oregon, 28 September 1975.
Wind energy is investigated as a source of energy. The wind energy program that is managed by the NASA-Lewis Research Center is described. The Lewis Research Center's Wind Power Office, its organization, plans, and status are discussed. $3.75. 31 pages.

The following reports were published by Sandia Laboratories, Albuquerque, New Mexico under contract AT(29-1)-789 and primarily address the Darrieus vertical axis system and wind data. All reports are available from the National Technical Information Service (NTIS) U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

1. SLA-74-0160 *Vertical-Axis Wind Turbine: How it Works*, Blackwell, B.F., April 1974.
   A qualitative description of how a vertical-axis wind turbine works is presented, and some of the advantages over a conventional propeller-type wind turbine are discussed. $4.00. 8 pages.

2. SLA-74-0154 *Blade Shape for a Troposkien Type of Vertical Axis Wind Turbine*, Blackwell, B.F., Reis, G.E., April 1974.
   The equations derived to define a troposkien (the shape a completely flexible cable assumes when it is spun at a constant angular velocity about a vertical axis to which its two ends are attached) are described. The implications of the solutions on the design of a vertical-axis wind turbine are discussed for cases where gravity is neglected. $4.25. 24 pages.

3. SLA-74-0298 *A Wind-Powered Fresh Water Condensation Air Conditioning, Mariculture, and Aquiculture Integrated System for Pacific Atolls*, Shuster, D.B., Dugan, V.L., Richards, R.H., June 1974.
   A facility designed to use the resources of the wind, the sun, and the sea to provide fresh water, food and cool air for the residents of Bikini and Eniwetok atolls or any other area having warm, moist air, suitable winds, and cold ocean water is described. $4.00. 11 pages.

4. SAND-74-0071 *Wind Energy Potential in New Mexico*, Reed, J.W., Maydew, R.C., Blackwell, B.F., July 1974.
   The history and states of wind turbines and the meteorological considerations of the wind energy potential in New Mexico are analyzed. $5.00. 40 pages.

5. SAND-74-0105 *Electrical System for Extracting Maximum Power from the Wind*, Veneruso, A.F., December, 1974.
   A proposed electrical system design is described that takes full advantage of the fact that the power available from the wind varies as the cube of the wind's speed. When a variable voltage-variable frequency ac polyphase approach is used to match the system's source and load characteristics, the electrical transmission system is capable of maximum power conversion. $4.50. 29 pages.

6. SAND-74-100 *Practical Approximations to a Troposkien by Straight Line and Circular Arc Segments*, Reis, G.E., Blackwell, B.F., March, 1975.
   Curves made up of circular arcs and straight lines which approximate troposkiens of interest in the design of crosswind-axis wind turbines were calculated for a variety of constraints. These curves were fitted to the troposkiens by numerical iteration by using both a least-squares and a least-maximum fit. $4.75. 34 pages.

7. SAND-74-0379 *Investigation of Rotation-Induced Stresses of Straight and of Curved Vertical-Axis Wind Turbine Blades,* Feltz, L.V., Blackwell, B.F., March 1975.
The feasibility of using straight blades for a Darrieus-type vertical-axis wind turbine is explored. Rotationally induced stresses for both straight and curved blades are compared. The scale-up implications are considered. $4.00. 20 pages.

8. SAND-75-0165 *Application of the Darrieus Vertical-Axis Wind Turbine to Synchronous Electrical Power Generation,* Banas, J.F., Kadlec, E.C., Sullivan, W.N., March 1975.
This report suggests that the Darrieus vertical-axis wind turbine may be particularly well-suited for driving a synchronous generator in parallel with a synchronizing electrical power network. Aerodynamic characteristics of the Darrieus wind turbine can be such that no torque regulation mechanisms are required on the turbine, providing the generator is properly sized. $4.00. 14 pages.

9. SAND-75-0166 *Wind Energy: A Revitalized Pursuit,* Blackwell, B.F., Feltz, L.V., March 1975.
The present state of wind energy development work has been reviewed and an estimate of the wind energy availability in the Great Plains area of the U.S. was presented. The usable wind energy available is greater than the 1973 total U.S. electrical energy consumption, but a probable factor limiting wind energy utilization will be availability of capital for new equipment. $4.00. 16 pages.

10. SAND-75-0204 *Methods for Performance Evaluation of Synchronous Power Systems Utilizing the Darrieus Vertical-Axis Wind Turbine,* Banas, J.F., Kadlec, E.G., Sullivan, W.N., April 1975. $4.00. 22 pages.

11. SAND-74-0378 *Nonlinear Stress Analysis of Vertical-Axis Wind Turbine Blades,* Weingarten, L.I., Nickell, R.E., April 1975.
A Darrieus type vertical-axis wind turbine with a troposkien blade shape was proposed by Sandia labs as an alternate to conventional horizontal axis, propeller-type machines. The troposkien (Greek for "turning rope") shape eliminates blade bending and thereby results in a more efficient, minimum material blade design. $4.00. 20 pages.

12. SAND-74-0177 *Some Geometrical Aspects of Troposkiens as Applied to Vertical-Axis Wind Turbines,* Blackwell, B.F., Reiss, G.E., May 1975. $4.00.

13. SAND-75-0348 *Wind Power Climatology of the United States,* Reed, J.W. June 1975. $7.60. 163 pages.

14. SAND-75-0530 *Engineering of Wind Energy Systems,* Banas, J.F., Sullivan, W.N., January 1976.
The engineering of wind energy systems is analyzed from the point of view of component selection and performance assessment. Combinations of two load types (variable and constant speed) and three turbine types connected by a fixed-gear-ratio transmission constitute the various systems investigated. $5.00. 27 pages.

IV. OTHER SOURCES OF BIBLIOGRAPHY AND REFERENCE MATERIAL

Energy From the Wind: Annotated Bibliography, Burke, B.L., Meroney, R.N., published by the Solar Energy Applications Laboratory College of Engineering, Colorado State University, Fort Collins, Colorado 80523, August 1975. A systematic search was made of the major abstracting and indexing tools from 1950 to 1974. This was augmented by references from other wind power bibliographies, publication lists and bibliographies of papers and suggestions from colleagues. Available from NTIS. Order No. NP-20712.

Energy from the Wind: Annotated Bibliography (First Supplement). April, 1976. This first supplement to ENERGY FROM THE WIND includes over 1100 new references to books, conference proceedings, journal articles, and technical reports on wind power. Over 800 of these new references were published between 1973 and 1977. As in the basic volume, the citations range from popular review and do-it-yourself projects for home and farm, to technical aerodynamic studies and reports on projects for large-scale production for power networks. Available from Colorado State University, Publications, Engineering Research Center, Fort Collins, Colorado 80523 $10.00 (domestic) $11.00 (foreign).

Initial Wind Energy Data Assessment Study, Changery, M.J., published by the United States Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), May 1975.
Results of a Data Survey and Recommendations and Conclusions of the Data Assessment Meeting Held at the National Climatic Center, Ashville, North Carolina, July 29-31, 1974. Available from NTIS. $ 6.00 132 pages. Order No. PB 244 132. NSF-RANN-75-020.

Solar Energy and Wind Power. A bibliography with abstracts. Report for 1964 - June 1974. Lehmann, E.J., Ringe, A.C. Published by NTIS, July, 1974.
Contains 154 selected abstracts, including 54 concerning wind power, covering its future, conversion systems, energy storage, propeller design and applications. Many abstracts are of recent NASA translations of European and Russian research conducted from 1934 to 1959. Available from NTIS. $20.00 162 pages.

Wind Energy: A Bibliography with Abstracts and Keywords, Van Steyn, Rene, published by Eindhoven University of Technology, Eindhoven, The Netherlands, July 1975. Two sections. Available from the Library Administration, University of Technology, Postbox 513, Eindhoven, Netherlands; $8.00 (Europe); $12.00 (outside Europe).

Wind Energy Utilization: A Bibliography with Abstracts, Cumulative volume 1944/1974.
Citations in this wind energy bibliography are listed under the following headings: general, utilization, wind power plants, wind power generators, wind machines, wind data and properties, energy storage, and related topics. Indexes are included for authors, corporate sources, titles and key words. Available from NTIS; $28.25. 503 pages.

GENERAL INTEREST INFORMATION ON WIND ENERGY

The following books and articles contain general interest and semi-technical information on wind energy systems and would be of interest to those contemplating building, buying or installing wind energy systems. They are available through many libraries, bookstores, or the publishers. Prices are not noted since they may vary. In addition, most manufacturers and distributors have material available, usually at some nominal charge due to the volume of inquiries.

Power From the Wind, Palmer Cosslett Putnam; Van Nostrand, Reinhold, Company, 1948. The story of the construction of the world's largest windmill. Also contains information on the fundamentals of wind systems.

The Generation of Electricity by Wind Power, E. W. Golding and R. I. Harris. John Wiley & Sons, Inc., New York, 1976. An account of the research and development of wind power in Great Britain and other countries up to 1955. Contains basic information on wind power, including its history. Discusses the siting, output, subsystems, performance and economics of wind systems. Selected bibliography. (First published in 1955)

Wind-Catchers, American Windmills of Yesterday and Tomorrow, Volta Torrey, The Stephen Greene Press, Brattleboro, Vermont, 1976. Describes dozens of American wind turbines of the past and present - from small home-made units to the NASA/ERDA Plumbrook test unit.

Energy Book #1 Running Press, 38 South 19th St., Philadelphia, Pa., 19103. Includes a description of wind and solar energy systems along with information on commercially available plans and systems.

Energy Primer: Solar, Water, Wind, and Biofuels, Richard Merrill, et al., eds., Portola Institute, 540 Santa Cruz, Menlo Park, California 94025. A description of these several energy forms with information on plans, commercial equipment, home building information and additional references.

Marks Standard Handbook for Mechanical Engineers, McGraw-Hill Book Company, several editions. Contains basic equations for wind power and general technical information on all areas of engineering needed in designing mechanical systems.

Planning a Wind Powered Generating System. Enertech Corporation, P.O. Box 420, Norwich, Vermont 05055. A practical guide to selecting a small system to meet the needs of the average household, including estimation of power requirements and details of site, tower and storage battery selections. A "cookbook" for the handyman.

Popular Science, November 1972. Contains considerable information on designing and constructing individual aerogenerators.

Simplified Wind Power Systems for Experiments, J. Park, Box 4301, Sylmar, California 91342.

Wind Power, Daniel M. Simmons, Noyes Data Corporation, Park Ridge, New Jersey, 1975. Volume No. 6 of the Energy Technology Review Series. A compendium of recent studies conducted by industrial and engineering firms or universities under the auspices of various government agencies.

Wind Power: Information and Planning Manual for Wind Driven Electric Power Systems, Charles D. Sejverson and John G. Symons; Wind Power, Box 233, Mankato, Minnesota 56001. Contains information on building, siting, and operating small wind systems for farms and homes.

Organizations

Wind Energy Society of America, 1700 East Walnut Street, Pasadena, California 91106. An organization of both active researchers as well as persons with a general interest in wind energy.

American Wind Energy Association, 21243 Grand River, Detroit, Michigan 48219. An organization of both manufacturers of systems and subsystems as well as persons with a general interest in wind energy.

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